

17/PRs

JCO5 Rec'd PCT/PTO 04 OCT 2005

10/ 551 993

## DESCRIPTION

### METHODS OF PRODUCING AN ALUMINA FILM MAINLY IN $\alpha$ CRYSTAL STRUCTURE AND THE MULTILAYER FILM THEREOF

#### FIELD OF THE INVENTION

The present invention relates to a method of producing an alumina film mainly in  $\alpha$  crystal structure to be deposited on wear-resistant products such as cutting tool, sliding parts, and die and a method of producing a multilayer film-deposited product by forming an alumina film mainly in  $\alpha$  crystal structure on the outmost layer of the product by the method above, and in particular, to a useful production method that allows production of an alumina film mainly in  $\alpha$  crystal structure (hereinafter, referred to simply as "quasi- $\alpha$ -alumina film") under a low-temperature condition that does not impair the properties of the substrate, independent of the kind of the substrate such as the cutting tool or the sliding parts.

The alumina film obtained by the present invention can be applied to the various applications described above, but the invention will be described hereinafter, applying it mainly to cutting tool as a typical example.

#### BACKGROUND OF THE INVENTION

Generally, substrates, for example of high-speed steel and cemented carbide, having a hard film such as of titanium nitride or titanium aluminum nitride formed on the surface thereof by physical vapor deposition method (hereinafter, referred to as PVD method), chemical vapor deposition method (hereinafter, referred to as CVD method), or the like have been used as cutting tools and sliding parts, for which superior wear resistance and sliding property are demanded.

In particular, in case of application as a cutting tool that demands high wear and heat resistance (oxidation resistance at high temperature) from the hard film, titanium aluminum nitride (TiAlN) that is superior in both of these properties has been used widely as a coating material for applications such as cemented carbide tools, the edge of which becomes heated to high temperature during machining. The reason for such advantageous properties of TiAlN is that the TiAlN film is improved in heat resistance by the action of aluminum contained in the film and exhibits excellent wear and heat resistance consistently up to a high temperature of approximately 800°C. Various TiAlN's different in the compositions of Ti and Al have been used as the TiAlN films, but most of them have a composition in which they are superior in both properties, that is, a Ti:Al atomic ratio in the

range of 50:50 to 25:75.

Meanwhile, the edge of a cutting tool or the like is occasionally heated to a temperature of 1,000°C or higher during machining. Under such circumstance, because the TiAlN film alone is not sufficiently effective as it is in ensuring heat resistance, it is often practiced to form an alumina layer additionally on a TiAlN film for ensuring heat resistance, as disclosed, for example, in U.S. Patent No. 5879823.

Alumina has various crystal structures, depending on temperature, but all of the crystal structures are in the thermally metastable state. However, in the case of a cutting tool, the temperature of the edge fluctuates in a wide range from room temperature to 1,000°C or higher during machining, which causes transformation in the crystal structure of alumina and consequently leads to problems such as the cracking and delamination of film. However, alumina in the  $\alpha$  crystal structure that is formed by CVD at a higher substrate temperature of 1,000°C or more, if once formed, retains its thermally stable structure, independently of the temperature thereafter. Thus, deposition of an alumina film in the  $\alpha$  crystal structure is regarded as an effective means of providing heat resistance to cutting tools and others.

However as described above, it is necessary to heat the substrate to 1,000°C or higher to form alumina in the  $\alpha$  crystal structure, which restricts the kind of compatible substrates. It is because some substrates soften and lose its favorable properties as a substrate for wear-resistant products, depending on its kind, when exposed to a high temperature of 1,000°C or higher. Even high heat-resistant substrates including cemented carbides also exhibit problems such as deformation, when exposed to such a high temperature. In addition, practical temperature range for use of the hard films such as TiAlN film that are formed on substrate as a wear-resisting film is generally, approximately 800°C at the highest, and such films may degenerate and lead to deterioration in wear resistance when exposed to a high temperature of 1,000°C or higher.

For overcoming such problems, U.S. Patent No. 5310607 reported that it was possible to obtain a  $(Al,Cr)_2O_3$  composite crystal having a hardness as high as that of the alumina described above in a lower temperature range of 500°C or lower. However if the work material contains iron as the principal component, Cr existing on the surface of the composite crystal film often reacts with iron in the work material chemically during machining, leading to enhanced consumption of the film and reduction of the lifetime.

Separately, O. Zywitzki, G. Hoetzs, et al. reported in "Surf. Coat.

Technol." (86-87, 1996, p. 640-647) that it was possible to form an aluminum oxide film in the  $\alpha$  crystal structure at 750°C by performing reactive sputtering by using a pulse power supply having a high output (11 to 17 kW). However, it is inevitable to expand the capacity of pulse power supply for obtaining aluminum oxide in the  $\alpha$  crystal structure by this method.

As a method overcoming such problems, Japanese unexamined patent publication No. 2002-53946 discloses a method of forming an oxide film having a film thickness of at least 0.005  $\mu\text{m}$  in the corundum structure ( $\alpha$  crystal structure) having a lattice parameter of 4.779Å or more and 5.000Å or less as an underlayer and forming an alumina film in the  $\alpha$  crystal structure on the underlayer. The patent application above shows that the component for the oxide film is preferably  $\text{Cr}_2\text{O}_3$ ,  $(\text{Fe,Cr})_2\text{O}_3$  or  $(\text{Al,Cr})_2\text{O}_3$ ; more preferably  $(\text{Fe}_x, \text{Cr}_{(1-x)})_2\text{O}_3$  (wherein,  $0 \leq x \leq 0.54$ ) when it is  $(\text{Fe,Cr})_2\text{O}_3$  and  $(\text{Al}_y, \text{Cr}_{(1-y)})_2\text{O}_3$  (wherein,  $0 \leq y \leq 0.90$ ) when it is  $(\text{Al,Cr})_2\text{O}_3$ .

It also indicates that it is effective to form a film of a composite nitride containing Al and one or more elements selected from the group consisting of Ti, Cr, and V as a hard film, a film of  $(\text{Al}_z, \text{Cr}_{(1-z)})\text{N}$  (wherein,  $0 \leq z \leq 0.90$ ) as an intermediate layer thereon which forms an oxide film having the corundum structure ( $\alpha$  crystal structure) by further oxidizing the film above, and then form alumina in the  $\alpha$  crystal structure on the oxide film.

The inventors proposed various methods for forming an alumina film mainly in  $\alpha$  crystal structure on a hard film (for example, Japanese Patent Application No. 2002-233848).

However, when the methods proposed by the inventors are applied to various kinds of substrates other than hard films, it was not possible to obtain a quasi- $\alpha$ -alumina film, depending on the kind of substrate. In addition when an alumina film is formed at a temperature of about 700°C in the relatively lower temperature range on the hard film above, which usually allows generation of the quasi- $\alpha$ -alumina film, the ratio of the  $\gamma$  to  $\alpha$  crystal structure increased in the alumina film obtained. Experimental results confirming the description above will be described below in detail.

First, the following three substrates (1) to (3) were prepared and the following experiments A and B were performed.

(1) Si wafer

(2) Cemented carbide substrate (12.7 mm  $\times$  12.7 mm  $\times$  5 mm) polished to mirror surface (Ra: approximately 0.02  $\mu\text{m}$ ) having a 2- to 3- $\mu\text{m}$  TiAlN ( $\text{Ti}_{0.55}\text{Al}_{0.45}\text{N}$ )

hard film formed thereon by the arc ion-plating method (hereinafter, referred to as AIP method) as a hard film

(3) cemented carbide substrate treated similarly to the substrate (2) having a 2- to 3- $\mu\text{m}$  CrN film formed thereon by the AIP method as a hard film.

#### <Experiment A>

Each substrate was first oxidized, and then, an alumina film was formed thereon. The substrate was oxidized and the alumina film was formed in the vacuum deposition device shown in Figure 1 (AIP-S40 hybrid coater machine, manufactured by Kobe Steel) equipped with an AIP cathode (indicated by No. 7 in Figure 1 below), a magnetron-sputtering cathode, a heater heating mechanism, a substrate-rotating mechanism, and others.

The substrate was oxidized as follows: A sample (substrate) 2 was connected to each planetary revolving jig 4 on the revolving table 3 in the device 1; the device was evacuated almost to the vacuum state; and the sample was heated to 750°C with a heater 5 placed in the center of the device and heaters 5 placed on the internal side wall 2 of the device. After the sample is heated to a particular temperature, an oxygen gas was introduced into the device 1 to a pressure of 0.75 Pa at a flow rate of 300 sccm, and the sample was oxidized while heated in the same condition for 20 minutes.

An alumina film was formed as follows: An alumina film of approximately 2  $\mu\text{m}$  in thickness was formed by the reactive sputtering method, specifically by applying a pulse DC power of approximately 2.5 kW respectively to the two sputtering cathodes 6 having an aluminum target shown in Figure 1, at a substrate temperature similar to that in the oxidation step in an argon and oxygen environment. The alumina film was formed at a discharge condition in a so-called transition mode, i.e., by controlling the discharge voltage and the flow rate ratio of argon/oxygen by plasma emission spectroscopy.

The crystal structure of the alumina film formed on the outmost layer was identified by analyzing the surface of the thin film thus formed with an X-ray diffractometer. Figure 2 shows the thin-film X-ray diffraction pattern of the alumina film formed when the substrate (2) (TiAlN film) was used; Figure 3, when the substrate (3) (CrN film) was used; and Figure 4, when the substrate (1) (Si wafer) was used.

In Figure 2, there are diffraction peaks indicating TiAlN and lower diffraction peaks indicating alumina in the  $\gamma$  crystal structure (hereinafter, referred

to as " $\gamma$ -alumina peak"), but the diffraction peaks indicating alumina in the  $\alpha$  crystal structure (hereinafter, referred to as " $\alpha$ -alumina peak") are higher, suggesting that a quasi- $\alpha$ -alumina film is formed on the TiAlN film. Figure 3, wherein the  $\alpha$ -alumina peaks are higher, also indicates that a quasi- $\alpha$ -alumina film is formed also on the CrN film. In Figure 3, peaks indicating chromium oxide formed by oxidation of the surface of the CrN film were also observed.

In contrast, there is no  $\alpha$ -alumina peak observed in Figure 4, suggesting that an alumina film mainly in the  $\gamma$  crystal structure is formed on the Si wafer.

#### <Experiment B>

Then, an alumina film was formed on each of the substrates (1) to (3) under the condition same as that of the experiment A, except that the substrate temperature was 700°C slightly lower than that in the experiment A, and the alumina film obtained was analyzed with a thin-film X-ray diffractometer. The results for the substrate (2) (TiAlN film) are shown in Figure 5; those for the substrate (3) (CrN film), in Figure 6; and those for the substrate (1) (Si wafer), in Figure 7.

Although both films in Figures 5 and 2 were formed on the same TiAlN film, it is apparent from the Figures that an alumina film formed in a lower temperature range has a higher intensity ratio of  $\gamma$  to  $\alpha$ -alumina peak, or a higher content of alumina in the  $\gamma$  crystal structure in the alumina formed, as shown in Figure 5.

In addition, similar results were obtained when the substrate (3) (CrN film) was used. It is obvious from comparison between Figures 6 and 3 above, that there are in Figure 6  $\gamma$ -alumina peaks not found in Figure 3, and that alumina in the  $\gamma$  crystal structure is easily formed when the film-forming temperature is in a lower temperature range.

When the substrate (1) (Si wafer) is used, there were only  $\gamma$ -alumina peaks observed as alumina peaks in Figure 7, similarly to when the film-forming temperature was 750°C (Figure 4 above), indicating that only alumina in the  $\gamma$  crystal structure was formed at the film-forming temperature intended by the present invention.

After similar experiments by changing other conditions as well, the inventors have found that it was possible to form alumina in the  $\alpha$  crystal structure, most easily when the substrate surface has a film containing Cr such as CrN and next easily when the substrate surface has a film containing Al such as TiAlN or Ti such as TiN or TiCN; and that it is also possible to form alumina in the  $\alpha$  crystal

structure, together with alumina in the  $\gamma$  crystal structure, even on substrates of high-speed steel or cemented carbide whereon no such a film was formed in the past. However, only alumina in the  $\gamma$  crystal structure was formed on a Si wafer, no matter how the condition was altered.

An object of the present invention, which was made under the circumstances above, is to provide a method of forming a quasi- $\alpha$ -alumina film not only on a substrate having a TiAlN film, CrN film, or the like formed on the surface thereof but also on a substrate such as a Si wafer, which hitherto allowed deposition only of alumina in the  $\gamma$  crystal structure at a temperature of approximately 800°C or lower, at a relatively low temperature without deformation or decomposition of the substrate.

The inventors believe that it becomes possible to form a quasi- $\alpha$ -alumina film in a lower temperature range, independently of the kind of substrate, by establishing a method of forming a film on a substrate resistant to deposition of a quasi- $\alpha$ -alumina film in this manner,

Another object of the present invention is to provide a method of forming the quasi- $\alpha$ -alumina film on CrN or TiAlN that allows deposition of  $\alpha$ -alumina at a lower film-forming temperature without contamination, for example, by alumina in the  $\gamma$  phase.

## SUMMARY OF THE INVENTION

The method of producing an alumina film mainly in  $\alpha$  crystal structure according to the present invention is characterized by processing the surface of a substrate with a ceramic powder mainly having the crystal structure same as that of alumina in the  $\alpha$  crystal structure in forming the alumina film mainly in  $\alpha$  crystal structure on the substrate (including a substrate having a film previously formed thereon).

The ceramic powder is preferably an oxide ceramic powder, preferably a ceramic powder having the same corundum structure ( $\alpha$  crystal structure) as the alumina mainly in the  $\alpha$  crystal structure, and more preferably alumina powder in the  $\alpha$  crystal structure having an average particle diameter of 50  $\mu\text{m}$  or less.

The substrate may have on the surface thereof a film of one or more compounds selected from the group consisting of compounds of one or more elements selected from the group consisting of the elements in Groups 4a, 5a and 6a in the periodic table, Al, Si and Y with one or more elements of C, N, B, and O, the solid solutions thereof, and compounds of one or more elements of C, N, and B.

Typical examples thereof include substrates having a hard film containing one or more compounds selected from the group consisting of TiN, TiC, TiCN, TiAlN and TiAlCrN formed on the surface thereof.

These step of treating a substrate surface includes, for example, a step of polishing the substrate surface by using the ceramic powder (preferably the alumina powder), a step of immersing and ultrasonically treating the substrate in a liquid containing the ceramic powder (preferably the alumina powder) dispersed, and the like.

The alumina film is preferably formed by a gas-phase growth method, and any method selected from the group consisting of CVD, PE-CVD, sputtering, ion plating, and vapor deposition may be used as the gas-phase growth method.

Accordingly, the present invention provides a method of producing a multilayer film-deposited product characterized by forming an alumina film mainly in a crystal structure on the film described above, and a method of producing a multilayer film-deposited product, characterized by including

- (1) a step of forming a hard film containing one or more compounds selected from the group consisting of TiN, TiC, TiCN, TiAlN and TiAlCrN on a substrate,
  - (2) a step of treating the substrate surface with a ceramic powder mainly having the crystal structure same as that of alumina in the  $\alpha$  crystal structure, and
  - (3) a step of forming an alumina film mainly in a crystal structure on the substrate after the treatment,
- wherein the multilayer film-coated product is produced in that order.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic explanatory view (top view) illustrating a device used in working the present invention.

Figure 2 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a TiAlN film (film-forming temperature: 750°C).

Figure 3 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a CrN film (film-forming temperature: 750°C).

Figure 4 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer (film-forming temperature: 750°C).

Figure 5 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a TiAlN film (film-forming temperature: 700°C).

Figure 6 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a CrN film (film-forming temperature: 700°C).

Figure 7 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer (film-forming temperature: 700°C).

Figure 8 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer previously polished with alumina powder (film-forming temperature: 750°C).

Figure 9 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer previously immersed and ultrasonicated in ethanol containing dispersed alumina powder (film-forming temperature: 750°C).

Figure 10 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer previously polished with alumina powder (film-forming temperature: 700°C).

Figure 11 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer previously immersed and ultrasonicated in ethanol containing dispersed alumina powder (film-forming temperature: 700°C).

Figure 12 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer previously polished with diamond powder (film-forming temperature: 700°C).

Figure 13 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a Si wafer previously immersed and ultrasonicated in ethanol containing dispersed diamond powder (film-forming temperature: 700°C).

Figure 14 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a TiAlN film previously polished with alumina powder (film-forming temperature: 700°C).

Figure 15 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a TiAlN film previously immersed and ultrasonicated in ethanol containing dispersed alumina powder (film-forming temperature: 700°C).

Figure 16 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a TiAlN film previously polished with diamond powder (film-forming temperature: 700°C).

Figure 17 is a chart showing the thin-film X-ray diffraction pattern of an alumina film formed on a TiAlN film previously immersed and ultrasonicated in ethanol containing dispersed diamond powder (film-forming temperature: 700°C).

## BEST MODE FOR CARRYING OUT THE INVENTION

Under the circumstances above, the inventors studied intensively from all angles on a method of forming an alumina film mainly in a crystal structure on a



substrate in a relatively lower temperature range of about 800°C or lower, independently of the kind of the substrate. As a result, the inventors have found that in forming an alumina film on a substrate (including a substrate having a film formed thereon), it is particularly effective to process a substrate surface by using a ceramic powder mainly having the crystal structure same as that of alumina in the  $\alpha$  crystal structure (hereinafter, referred to simply as "pretreatment").

Such a finding was made on the basis of various experiments, and based on the facts obtained by the experiments, the mechanism, although not completely elucidated, is considered as follows:

The results of the experiments by the inventors suggest that the properties of the underlying substrate surface have a very important influence on generation of the crystal layer of alumina film,

Specifically, when the substrate surface having a TiAlN or CrN film thereon formed by AIP method, for example, is oxidized, the alumina in  $\alpha$  crystal structure is often formed on the substrate. Aluminum oxide is formed on the outmost layer of the TiAlN film by the oxidation and  $\text{Cr}_2\text{O}_3$  having the crystal structure same as that of alumina in  $\alpha$  crystal structure is formed on the outmost layer of the CrN film; and presence of these metal oxides seems to provide a condition favorable for generation of  $\alpha$ -alumina crystal nuclei during the initial phase of film formation.

On the contrary, as described above, when a Si wafer is used as the substrate, alumina in the  $\alpha$  crystal structure is not formed at all, even if the film is formed under the condition same as that for the TiAlN or CrN film. It is presumably because a thin and dense  $\text{SiO}_2$  film, which is formed on the surface of the Si wafer by oxidation of the Si wafer, is in a state unsuitable for generation of  $\alpha$ -alumina crystal nuclei.

However, even if a Si wafer was also used as the substrate, an quasi- $\alpha$ -alumina film was formed at a film-forming temperature in the range of 700°C and 750°C, if the Si wafer substrate before deposition of the alumina film was polished with alumina powder in the  $\alpha$  crystal structure or immersed and ultrasonicated in a liquid in which the powder is dispersed.

On the other hand, when a Si wafer was used as the substrate and a diamond paste (diamond powder), hard powder similar to alumina powder, was used replacing the alumina powder, no quasi- $\alpha$ -alumina film was formed. Also when zirconia or silica ( $\text{SiO}_2$ ) powder is used instead of the alumina powder in the similar treatment (ultrasonication), an alumina film mainly in  $\gamma$  crystal structure containing alumina in  $\alpha$  crystal structure in a smaller amount was formed.

The fact that the quasi- $\alpha$ -alumina film is formed on a Si wafer only when the wafer is treated with alumina powder in  $\alpha$  crystal structure suggests that fine scratches and dents reflecting the  $\alpha$  crystal structure of alumina powder are formed on the Si wafer or a trace amount of the alumina powder in  $\alpha$  crystal structure used is left on the substrate surface by the pretreatment and that the scratch and dent or the alumina powder remaining in a trace amount serve to start the generation of  $\alpha$ -alumina crystal nuclei during alumina deposition.

In another experiment, alumina films were formed on a substrate having a hard film of CrN, TiAlN, or the like on the surface thereof, instead of on the Si wafer, at a substrate temperature of 700°C similarly to above. As a result, when the pretreatment above is not done, a film containing mainly  $\alpha$ -alumina and a slight amount of  $\gamma$  phase alumina was formed on the CrN while a film mixed with  $\alpha$ - and  $\gamma$ -alumina was formed on the TiAlN. In contrast, when the surface of the hard film was pretreated with the alumina powder, the quasi- $\alpha$ -alumina film was formed both on CrN and TiAlN.

On the other hand, when the pretreatment was done using the powder of diamond, zirconia, or silica instead of the alumina powder, there was no effect to accelerate  $\alpha$ -crystallization observed when the alumina powder was used. The phenomena seem to be caused by the reason same as that when the experiments were done using the Si wafer as a substrate.

From the consideration above, the inventors have found that, in forming an alumina film on a substrate (including a substrate having a film formed thereon), it is effective to treat the substrate surface by using a ceramic powder mainly having the crystal structure same as that of alumina in the  $\alpha$  crystal structure.

Examples of the methods of treating the substrate surface include polishing of the substrate surface by using a ceramic powder such as alumina powder as in the experiment above, immersion and ultrasonication of the substrate in a liquid in which the powder is dispersed, and other similar processing methods including shot blasting, wet honing, barrel wear, and the like.

Examples of the ceramic powders for use in the pretreatment include metal oxides, metal nitrides, metal borides, metal carbides, metal carbide/nitrides, and the like; and specific examples thereof include alumina in  $\alpha$  crystal structure, the ceramic powders having the crystal structure same as that of the alumina in  $\alpha$  crystal structure such as  $\text{Cr}_2\text{O}_3$  and  $\text{Fe}_2\text{O}_3$ ; and the like. An alumina powder in  $\alpha$  crystal structure identical with that in the alumina film to be formed on the outmost layer is preferably used.

The size of the alumina powder is preferably smaller, from the purpose of forming a thin dense alumina film, and specifically, and the average particle diameter of the alumina used is preferably 50  $\mu\text{m}$  or less and more preferably 1  $\mu\text{m}$  or less.

Examples of the substrates for use in the present invention include Si wafer, cemented carbide, high-speed steel, glass, sintered cBN (cubic boron nitride), and the like, or the composites thereof carrying an additional film formed thereon. A film of one or more compounds selected from the group consisting of compounds of one or more elements selected from the group consisting of elements in Groups 4a, 5a and 6a in the periodic table, Al, Si and Y with one or more elements of C, N, B, and O; the solid solutions thereof; and compounds of one or more elements of C, N and B (for example, diamond, DLC, carbon nitride, and boron nitrides such as cBN, and boron carbide such as  $\text{B}_4\text{C}$ ), may be formed on the substrate surface. Typical examples thereof include hard films containing one or more compounds selected from the group consisting of TiN, TiC, TiCN, TiAlN and TiAlCrN.

In addition, in forming an alumina film, it is preferable to oxidize the substrate after the pretreatment according to the present invention, because the quasi- $\alpha$ -alumina film is formed more easily. In such a case, it is preferable to oxidize the substrate in an alumina film-deposition device, since it enables to form an alumina film subsequently on the substrate still retaining the temperature during the oxidation, thus leading to a preservation of the properties of the substrate and the film and a excellent productivity.

One of the favorable oxidation methods is a thermal oxidation method of oxidizing a substrate in an environment of an oxidative gas at a higher substrate temperature. Another favorable method that may be used is a method of irradiating an oxidative gas in the plasma state.

The thickness of the alumina film formed is preferably 0.1 to 20  $\mu\text{m}$ . It is because a thickness of 0.1  $\mu\text{m}$  or more is effective for ensuring the superior heat resistance of the alumina film, and the thickness is more preferably 0.5  $\mu\text{m}$  or more and still more preferably 1  $\mu\text{m}$  or more. However, an excessively larger thickness of the alumina film, which often results in generation cracks in the alumina film due to an internal stress formed therein, is not favorable. Accordingly, the film thickness is preferably 20  $\mu\text{m}$  or less, more preferably 10  $\mu\text{m}$  or less, and still more preferably 5  $\mu\text{m}$  or less.

The method of forming the alumina film is not particularly limited in the present invention, and may be any one of gas-phase growth methods such as CVD,

PE-CVD, sputtering, ion plating, and vapor deposition; among them, it is preferable to use the sputtering method, a PVD method allowing film deposition in a lower-temperature range; and reactive sputtering is particularly preferable, because it allows high deposition rate by using an inexpensive metal target.

The substrate temperature during deposition of the alumina film is not specified here, but as described above, deposition of an alumina film subsequently done after the oxidation step is preferably performed at a temperature of approximately 650 to 800°C.

The present invention allows deposition of the quasi- $\alpha$ -alumina film on various substrates without being restricted to film-coated substrates and thus, is applicable in a wide variety of fields: for example, production of multilayer film-coated parts such as cutting tool and sliding parts, by forming a quasi- $\alpha$ -alumina film on a substrate having a hard film, for example of TiAlN, thereon; use as a substitute for sapphire (single crystalline alumina), by forming the quasi- $\alpha$ -alumina film on a Si wafer substrate; production of parts superior in plasma resistance, by forming the quasi- $\alpha$ -alumina film on a quartz glass; use as a high-heat-resisting insulating film, by forming the quasi- $\alpha$ -alumina film on a heat resistant alloy; and use as a cutting tool or the like, by forming the quasi- $\alpha$ -alumina film directly on a cemented carbide, sintered cBN, or high-speed steel substrate.

## EXAMPLES

Hereinafter, the present invention will be described more specifically with reference to Examples, but it should be understood that the present invention is not restricted by the following Examples and all modifications that may be conducted in the scope of the descriptions above and below are also included in the technical scope of the present invention.

### <Example 1>

A Si wafer substrate (size: ca. 20 mm  $\times$  20 mm) was pretreated under each of the following three conditions (A) to (C) and washed to give a substrate having a clean surface; the substrate was then oxidized; and an alumina film was formed thereon. Alumina powder having an average particle diameter of 1  $\mu$ m and a composition of Al<sub>2</sub>O<sub>3</sub> of 99.7 mass % was used as the following alumina powder. The fact that the alumina powder mainly had  $\alpha$  crystal structure was confirmed separately by X-ray diffraction analysis.

(A) Without pretreatment

(B) The substrate surface is polished with a buff cloth coated with alumina

powder

(C) The substrate is immersed and ultrasonicated for 6 minutes in ethanol in which 0.25 g/mL of alumina powder is dispersed

Oxidation of the substrate and deposition of an alumina film were performed in the vacuum deposition device shown in Figure 1 (AIP-S40 hybrid coater machine, manufactured by Kobe Steel).

The substrate was oxidized in the following manner: A substrate 2 after the pretreatment above and normal washing was connected to one of the planetary revolving jigs 4 on the revolving table 3 of the device 1; the device was then evacuated almost into the vacuum state; the sample was heated to 750°C with a heater 5 placed in the center of the device and heaters 5 placed on the internal side wall 2 of the device. After the sample is heated to a particular temperature, an oxygen gas was introduced into the device 1 to a pressure of 0.75 Pa at a flow rate of 300 sccm, and the sample was oxidized while heated in the same condition for 20 minutes.

The oxidation and the alumina deposition described below were performed while revolving the table 3 shown in Figure 1 described above and rotating the planetary revolving jig 4 (substrate-holding pipe) placed thereon.

An alumina film was formed as follows: An alumina film of approximately 2  $\mu\text{m}$  in thickness was formed by a reactive sputtering method, specifically by applying a pulse DC power of approximately 2.5 kW respectively to the two sputtering cathode 6 having an aluminum target shown in Figure 1, at a substrate temperature similar to that in the oxidation step in an argon and oxygen environment. The alumina film was formed at a discharge condition in a so-called transition mode, i.e., by controlling the discharge voltage and the flow rate ratio of argon/oxygen by plasma emission spectroscopy.

The crystal structure of the alumina film formed on the outmost layer was identified by analyzing the surface of the thin film thus formed with an X-ray diffractometer. The results are shown in Figures 4, 8, and 9.

Figure 4 shows the results obtained under the condition (a), i.e., without the pretreatment according to the present invention, and as apparent from Figure 4, there is only alumina in  $\gamma$  crystal structure formed. In contrast, Figure 8 shows the results obtained when the substrate was polished under the condition (b) (polishing with alumina powder) and Figure 9 shows the results obtained when the substrate is pretreated under the condition (c) (immersion and ultrasonication in ethanol containing dispersed alumina powder); and these Figures 8 and 9 indicate that the

alumina films formed have the  $\alpha$  crystal structure mainly.

It was confirmed from the results above that it was possible to form a quasi- $\alpha$ -alumina film also on a substrate such as Si wafer, on which it was difficult to form such a quasi- $\alpha$ -alumina film by conventional methods, when the substrate was pretreated under the condition according to the present invention in forming the alumina film,

<Example 2>

The following two substrates (i) and (ii) were prepared.

(i) Si wafer

(ii) Cemented carbide substrate (12.7 mm  $\times$  12.7 mm  $\times$  5 mm) polished to mirror surface (Ra: approximately 0.02  $\mu$ m), washed by ultrasonic cleaning in an alkali tank and in a purified water tank, dried and formed with a TiAlN film of approximately 2  $\mu$ m in thickness thereon by AIP method

Then, the substrate was pretreated under one of the following five conditions (D) to (H) and washed to give a substrate having a clean surface, and then the substrate was processed in a similar manner to Example 1 above, except that the substrate was oxidized and an alumina film was formed thereon at a substrate temperature of 700°C (lower by 50°C than that in Example 1 above). Alumina powder similar to that used in Example 1 was used as the following alumina powder, and diamond powder having a particle diameter of 0.5  $\mu$ m was used as the following diamond powder (diamond paste).

(D) Without pretreatment

(E) The substrate surface is polished with a buff cloth coated with alumina powder

(F) The substrate is immersed and ultrasonicated for 6 minutes in ethanol dispersed with alumina powder

(G) The substrate surface is polished with a buff cloth coated with diamond powder

(H) The substrate is immersed and ultrasonicated for 6 minutes in an ethanol dispersed with diamond powder

The crystal structure of the alumina film formed on the outmost layer was identified by analyzing the surface of the film thus formed with a thin-film X-ray diffractometer.

First, results obtained when the Si wafers (i) were respectively pretreated under the conditions of D to H are shown in Figures 7 and 10 to 13. Figure 7 shows the results obtained under the condition (D), i.e., when the substrate was not

pretreated under the condition according to the present invention; and it is obvious from Figure 7 that an alumina film mainly in  $\gamma$  crystal structure was formed as the alumina film.

In contrast, Figure 10 shows the results obtained when the substrate was pretreated under the condition (E) (polishing with alumina powder), and Figure 11 when the substrate was pretreated under the condition (F) (immersion and ultrasonication in ethanolic dispersion of alumina powder); and Figures 10 and 11, wherein there are small  $\gamma$ -alumina peaks together with large  $\alpha$ -alumina peaks, showing that a quasi- $\alpha$ -alumina film was formed.

These results indicates that it is possible to form a quasi- $\alpha$ -alumina film even at a temperature of 700°C in the range lower than that of Example 1, by pretreating the substrate with the ceramic powder (alumina powder) according to the present invention.

As Comparative Examples, the results obtained when the substrate was pretreated under the condition (G) (polishing with diamond powder) are shown in Figure 12, and the results obtained when the substrate was pretreated under the condition (H) (immersion and ultrasonication in an ethanolic dispersion of diamond powder) in Figure 13.

In Figure 12, there are small  $\alpha$ -alumina peaks as well as large  $\gamma$ -alumina peaks, while in Figure 13, the peaks indicating alumina are all  $\gamma$ -alumina peaks, and thus both Figures indicate that a film mainly containing  $\gamma$ -alumina was formed.

Comparison between Figure 10 (polishing with alumina powder) and Figure 12 (polishing with diamond powder), and also between Figure 11 (ultrasonication by using alumina powder) and Figure 13 (ultrasonication by using diamond powder) reveals that the hard powder for use in pretreatment is preferably the alumina powder according to the present invention.

The results obtained when the substrate (ii) (cemented carbide having a TiAlN film formed thereon) was used as the substrate and pretreated under the conditions of D to H are shown in Figures 5 and 14 to 17.

Figure 5 shows the results obtained when the substrate was pretreated under the condition (D) (without pretreatment). Figure 5, wherein the  $\gamma$ -alumina peaks are relatively higher than  $\alpha$ -alumina peaks, indicates a mixture of both  $\alpha$  and  $\gamma$  crystal structures.

In contrast, Figure 14 shows the results obtained when the substrate was pretreated under the condition (E) (polishing with alumina powder) and Figure 15 when it was pretreated under the condition (F) (ultrasonication in ethanolic

dispersion of alumina powder); and Figures 14 and 15, wherein the  $\gamma$ -alumina peaks are very small, indicate that the quasi- $\alpha$ -alumina film was formed favorably.

As Comparative Examples, the results obtained when the substrate was pretreated under the condition (G) (polishing with diamond powder) are shown in Figure 16, and the results obtained when the substrate was pretreated under the condition (H) (ultrasonication in ethanolic dispersion of diamond powder) in Figure 17.

Figures 16 and 17, wherein  $\alpha$ -alumina peaks are smaller, indicate that the alumina film has a mixture of  $\alpha$  and  $\gamma$  crystal structures, a result almost identical with that when the substrate was not pretreated.

Further, by comparison between Figure 14 (polishing with alumina powder) and Figure 16 (polishing with diamond powder) and also between Figure 15 (ultrasonication by using alumina powder) and Figure 17 (ultrasonication by using diamond powder), it is obvious that use of the alumina powder according to the present invention is effective as the hard powder for use in pretreatment even when the alumina film is formed on a TiAlN film.

#### INDUSTRIAL APPLICABILITY

By the present invention, it is possible to form a quasi- $\alpha$ -alumina film easily at a relatively low temperature, independently of the kind of the substrate, not only on a substrate having a film such as of TiAlN or CrN formed thereon, but also on a substrate such as Si wafer whereon only alumina in  $\gamma$  crystal structure was formed traditionally at a temperature of approximately 800°C or lower,

In addition, when a substrate having a film, for example, of TiAlN or CrN formed on the surface thereof is used, it is possible to form a quasi- $\alpha$ -alumina film, even at a lower temperature at which a mixture of alumina in  $\gamma$  and  $\alpha$  crystal structures are easily formed.